

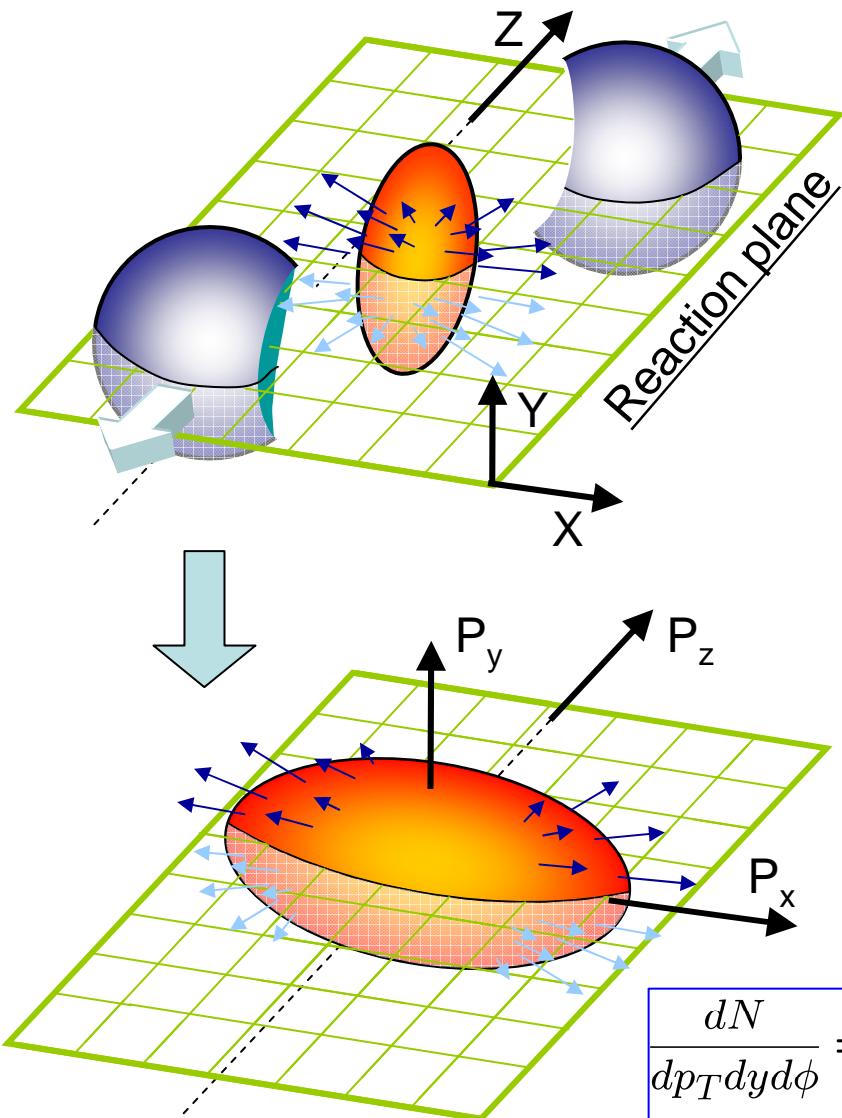
Elliptic Flow in PHENIX

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for the PHENIX collaboration

CIPANP 2006, Westin Rio Mar Beach
Puerto Rico
May 30 - Jun 3, 2006



Why Elliptic Flow ?



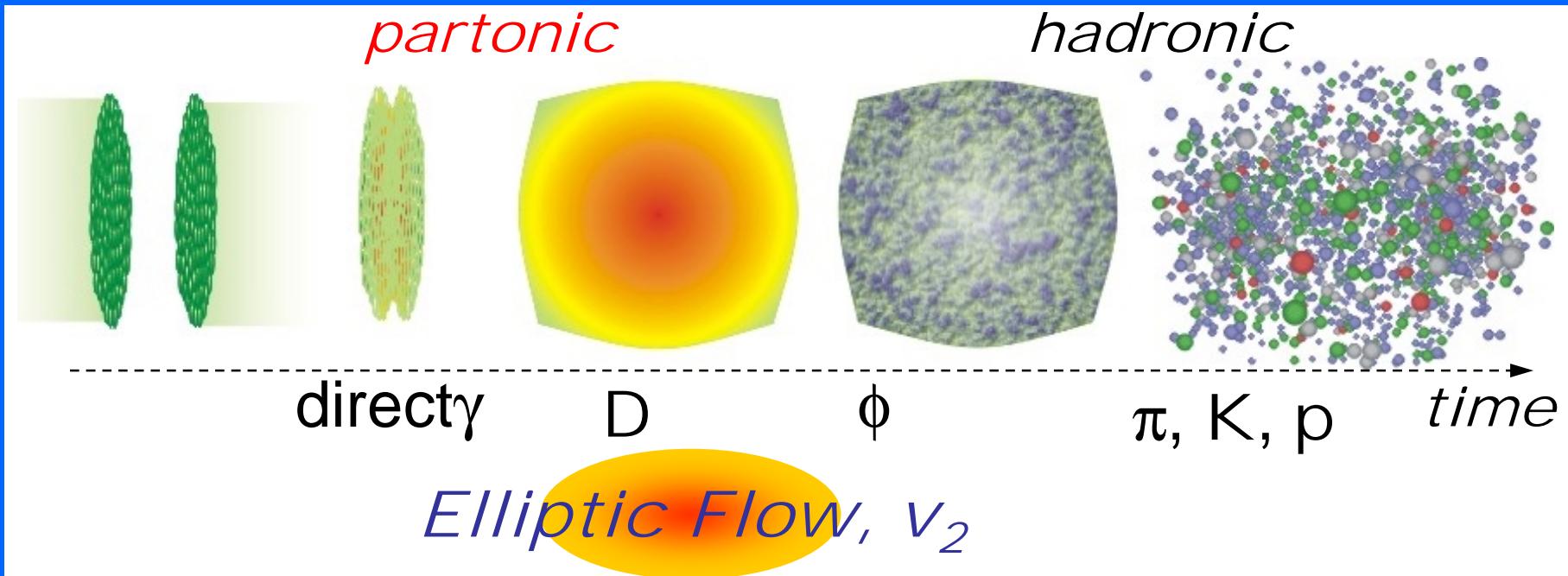
- *Study the properties of matter created at RHIC*
- *The probe for early time*
 - The dense nuclear overlap is ellipsoid at the beginning of heavy ion collisions
 - Pressure gradient is largest in the shortest direction of the ellipsoid
 - Spatial anisotropy → Momentum anisotropy
 - Signal is self-quenching with time
 - Elliptic flow (v_2) is defined by the 2nd coefficient of Fourier expansion

$$\frac{dN}{dp_T dy d\phi} = \frac{1}{2\pi} \frac{d^2 N}{dp_T dy} (1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi) + \dots)$$

$$v_2 = \langle \cos(2\phi) \rangle$$

Outline

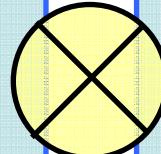
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Partonic degrees of freedom, Thermalization, ...

Elliptic Flow, v_2

- Bulk, early probe
- Charged hadrons give us a base line



ϕ Meson

- Small interaction cross section, long lived life time (~40 fm/c)

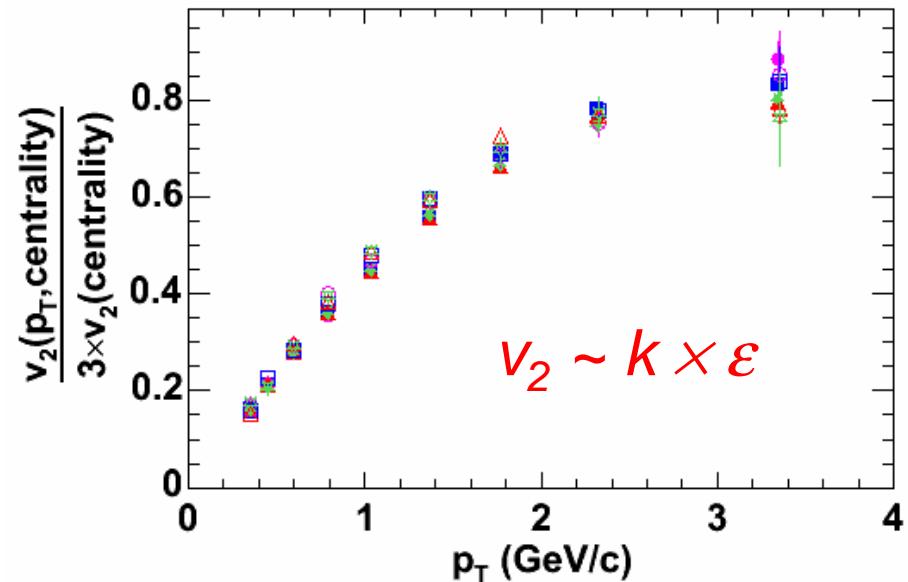
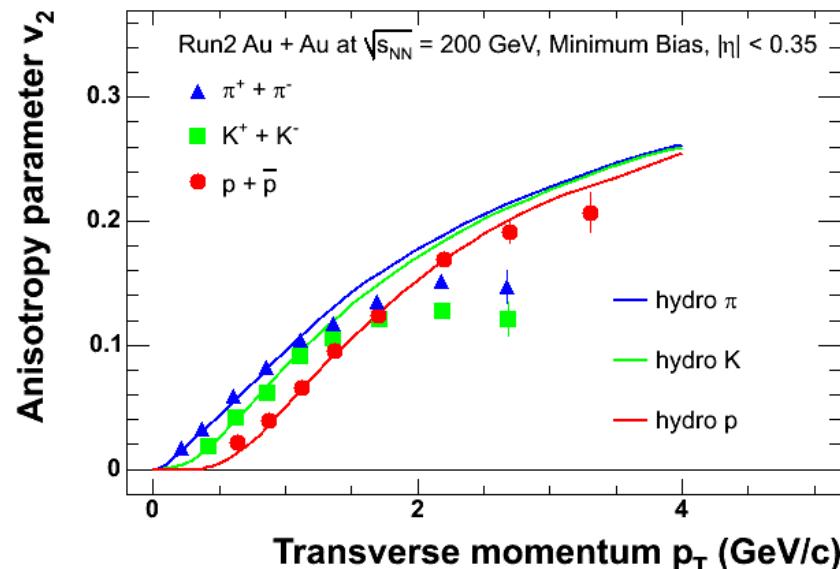
Penetrating probes

- Heavy flavor electrons (charm)
- Direct γ

Baseline : charged hadrons

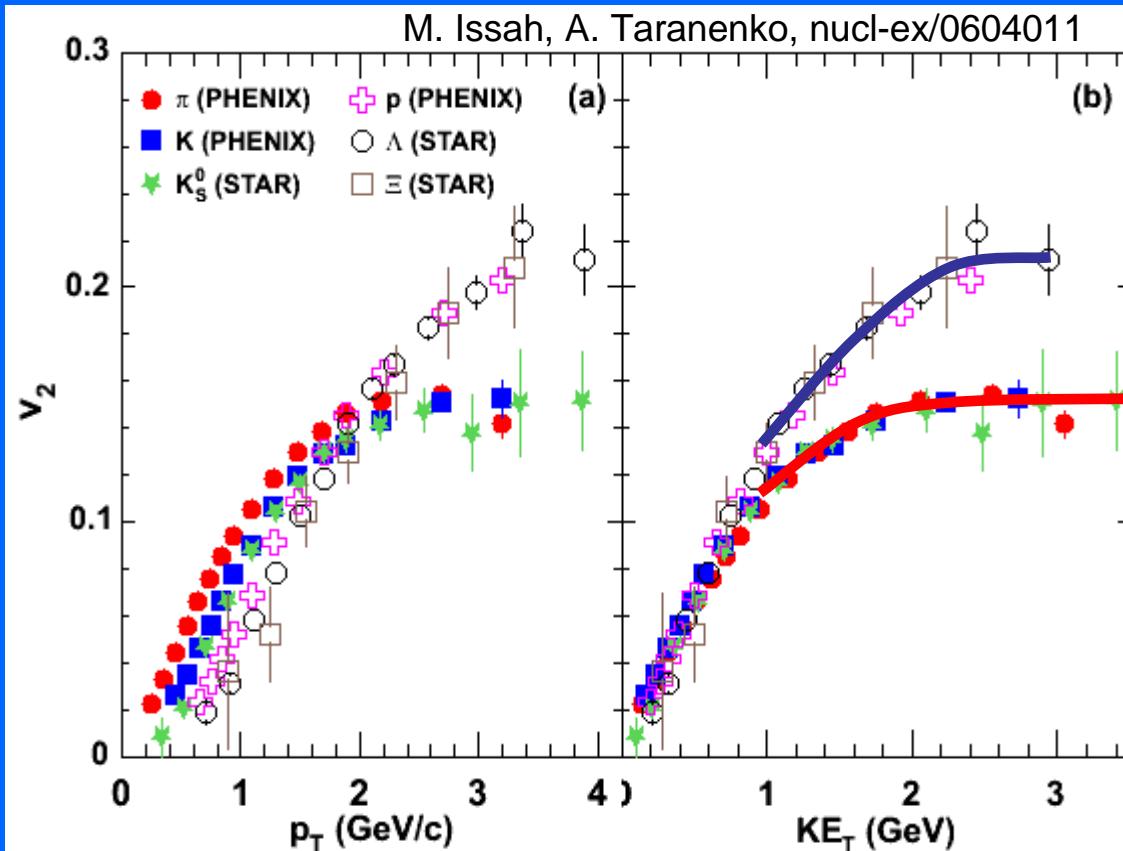
Charged hadrons, v_2 vs p_T

PHENIX : PRL 91, 182301 (2003)



- *Large elliptic flow at RHIC*
 - Consistent with hydrodynamics with rapid thermalization, $\tau \sim 1$ fm/c
 - v_2 scales initial eccentricity (ϵ) of reaction zone

Hydro scaling



Hydro scaling of v_2

K_s^0, Λ (STAR) : PRL 92, 052302 (2004)

Ξ (STAR) : PRL 95, 122301 (2005)

π, K, p (PHENIX) : preliminary

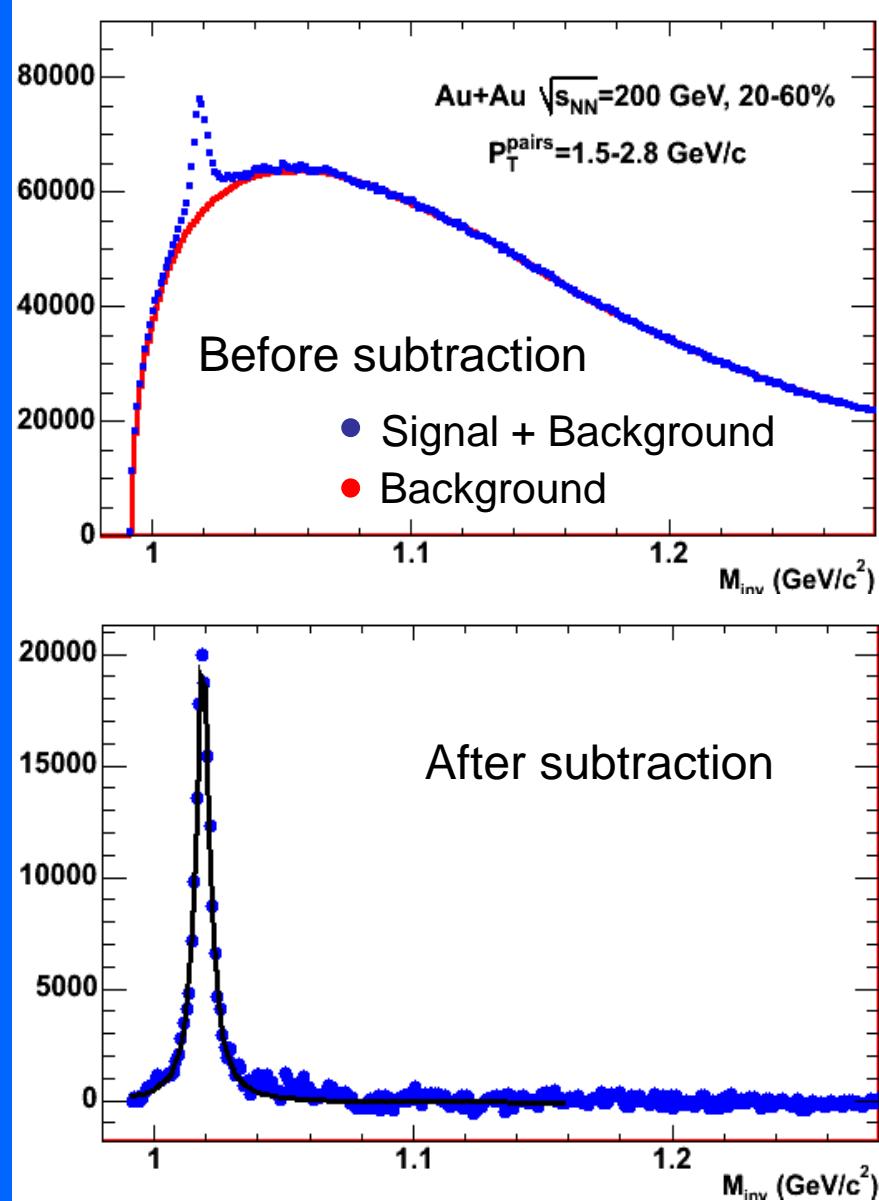
Meson v_2
Baryon v_2

* $KE_T \sim m_T - m_0$ at $y \sim 0$

- *Scaling holds up to $KE_T = 1$ GeV*
- *Meson/Baryon v_2*
 - Possible hint of partonic degrees of freedom

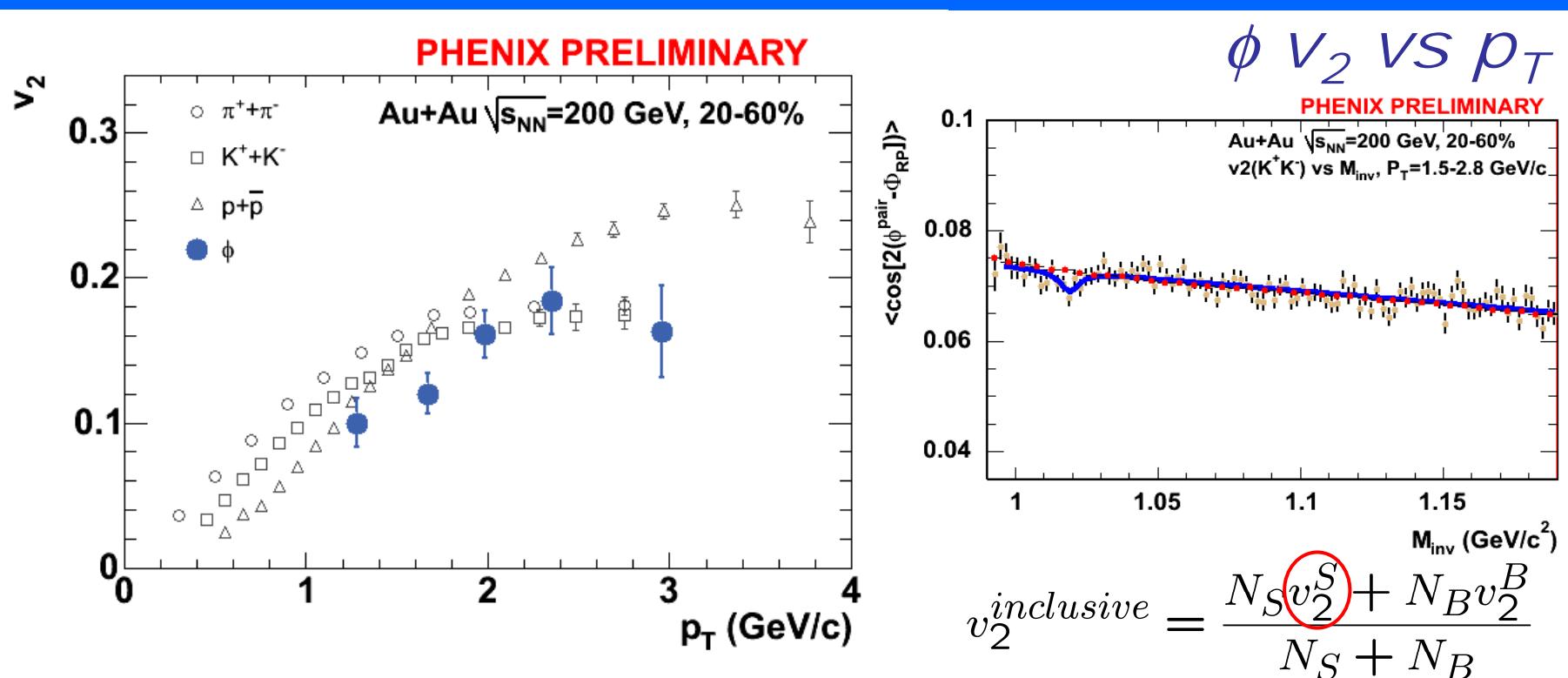
7. ϕ meson V_2

Clear ϕ signal



- ϕ reconstruction via $K^+ K^-$ decay channel
 - S/N ~ 0.3
- Centrality 20 – 60 %
 - S/N is good
 - Event plane resolution is good
 - Separation between meson/baryon v_2 is good
 - v_2 do not be varied too much.

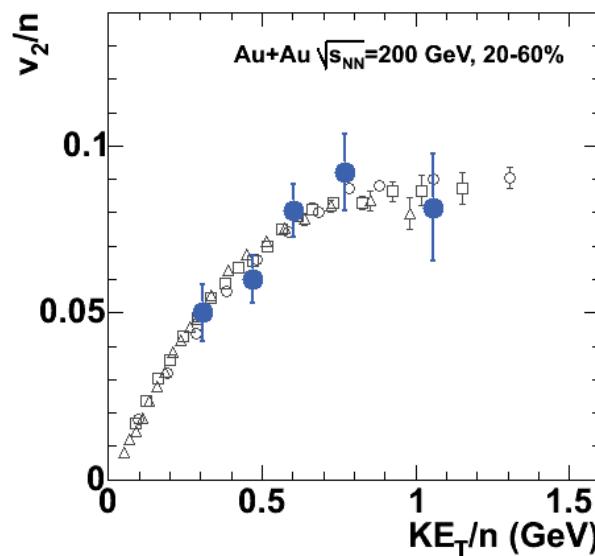
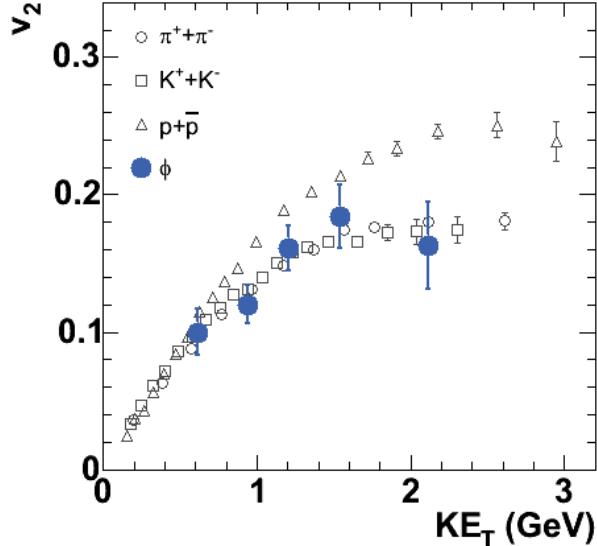
“Meson” type flow !



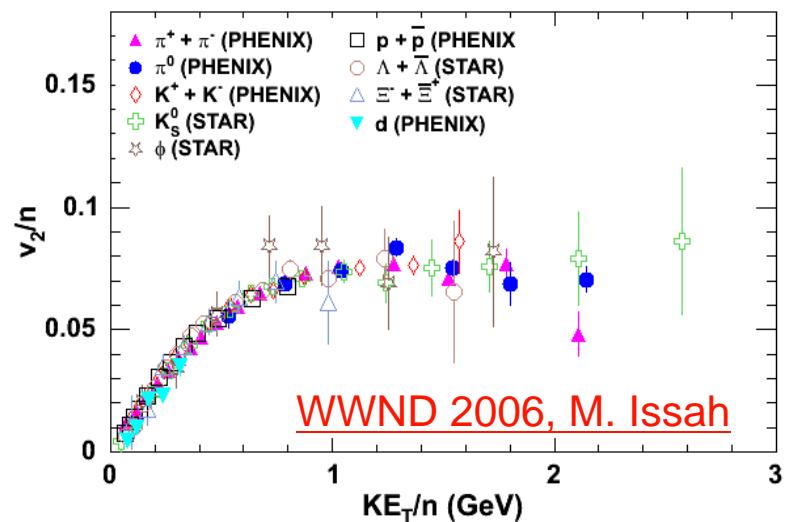
- Hydro. mass ordering for $p_T < 2$ GeV/c
- $v_2(\phi) \sim v_2(\pi), v_2(K)$ for $p_T > 2$ GeV/c
 - Mass \rightarrow Number of constituent quarks
 - Consistent with the description by quark coalescence, recombination models

Hint of partonic d.o.f

Hydro scaling of v_2



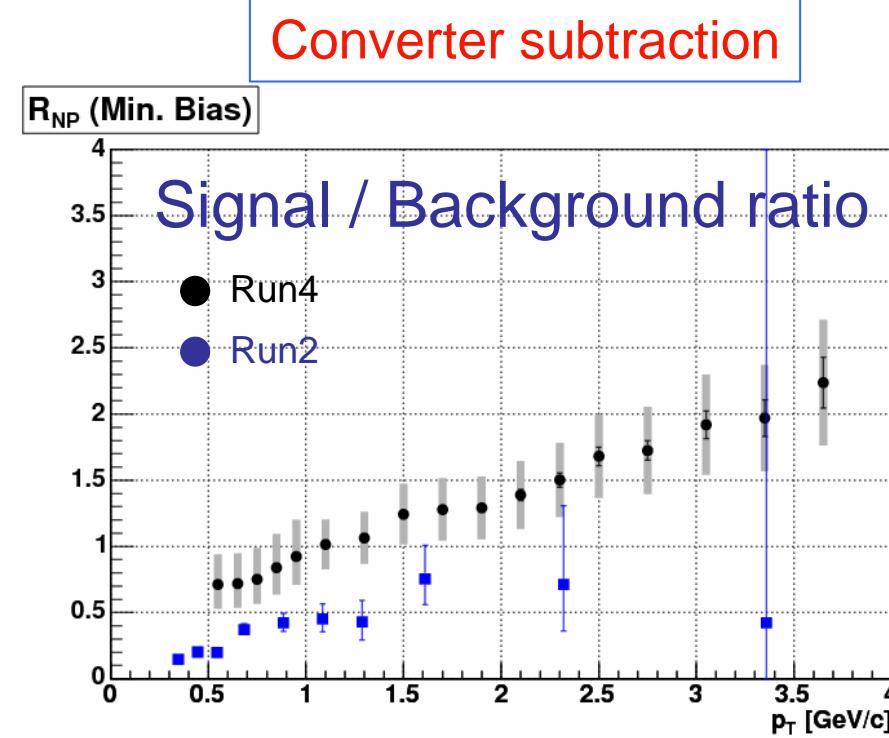
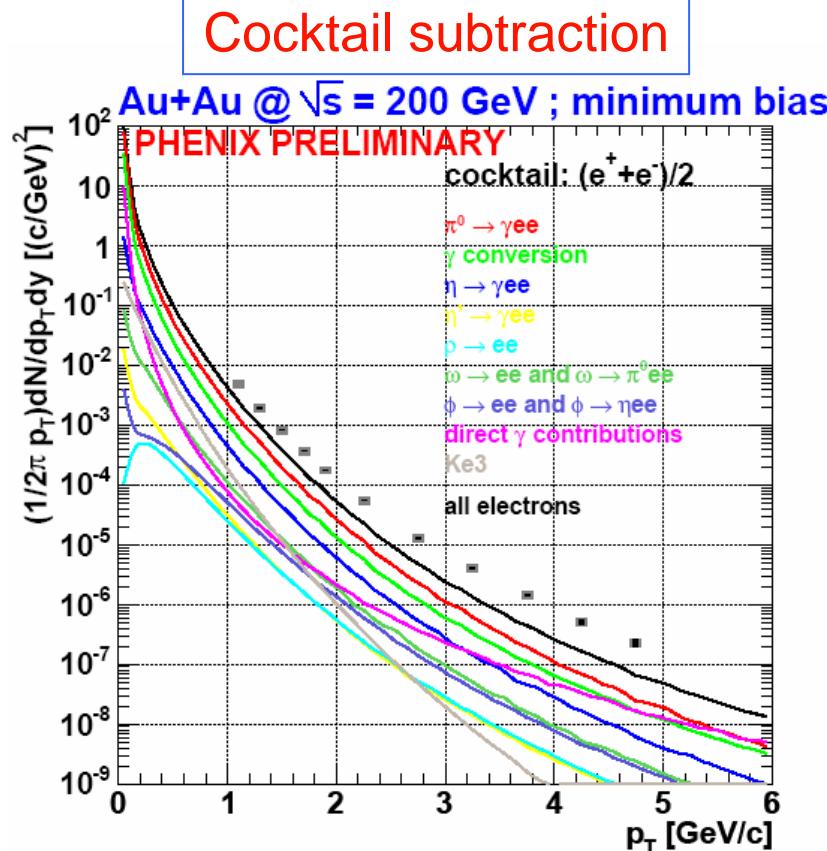
K^0_S, Λ (STAR) : PR 92,
052302 (2004)
 Ξ (STAR) : PRL 95, 122301
(2005)
 ϕ (STAR) : preliminary
 π, K, p, π^0, d (PHENIX) :
preliminary



- *Hydro + N_{quark} scaling*
 - Works for a broad range of KE_T
 - ϕ meson also follow the scaling
- Partonic degrees of freedom**

2. Heavy flavor e/ν

Clean heavy flavor electron

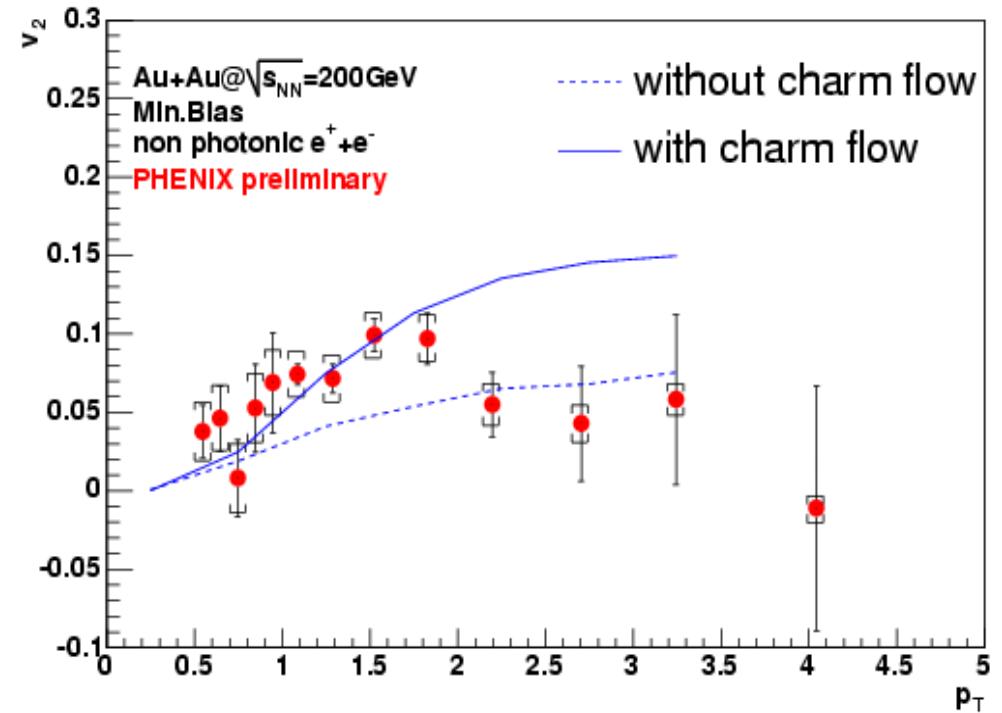
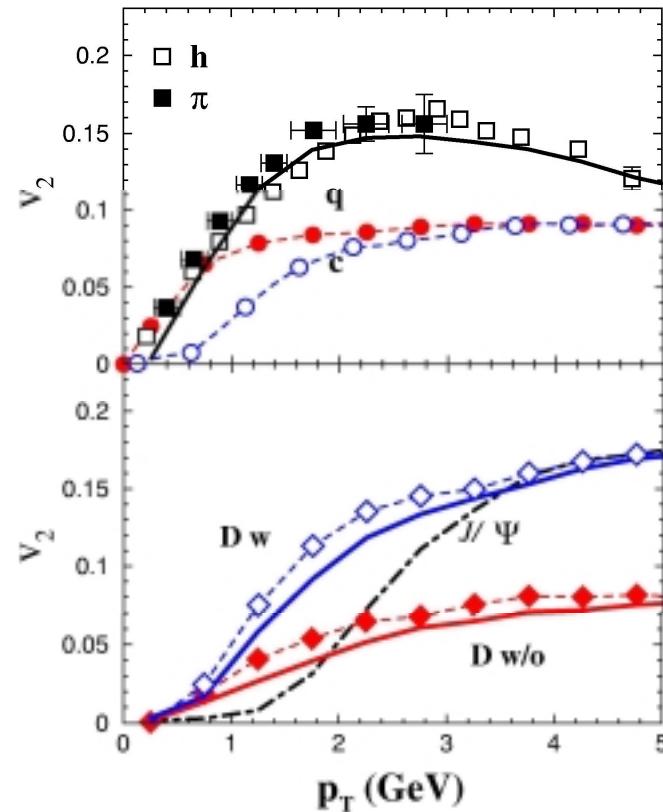


- Two different techniques show an excess heavy flavor electron signal
 - Signal/Background > 1 for $p_T > 1$ GeV/c

Hint of Charm flow

V. Greco, C. M. Ko, R. Rapp: PL B 595, 202 (2004)

$e \nu_2$ vs p_T

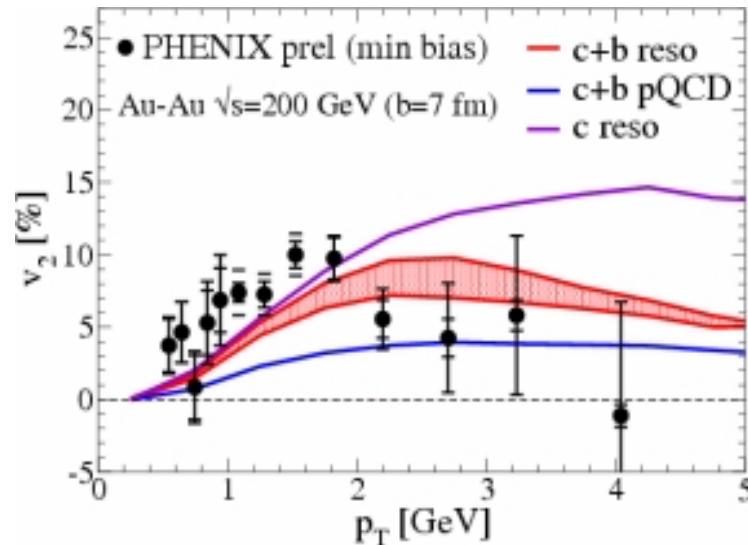


- *Data indicate finite v_2 of charm quark*
 - Suggest thermalization of c quark as well as light quarks
- *What is the origin of high p_T drop ?*

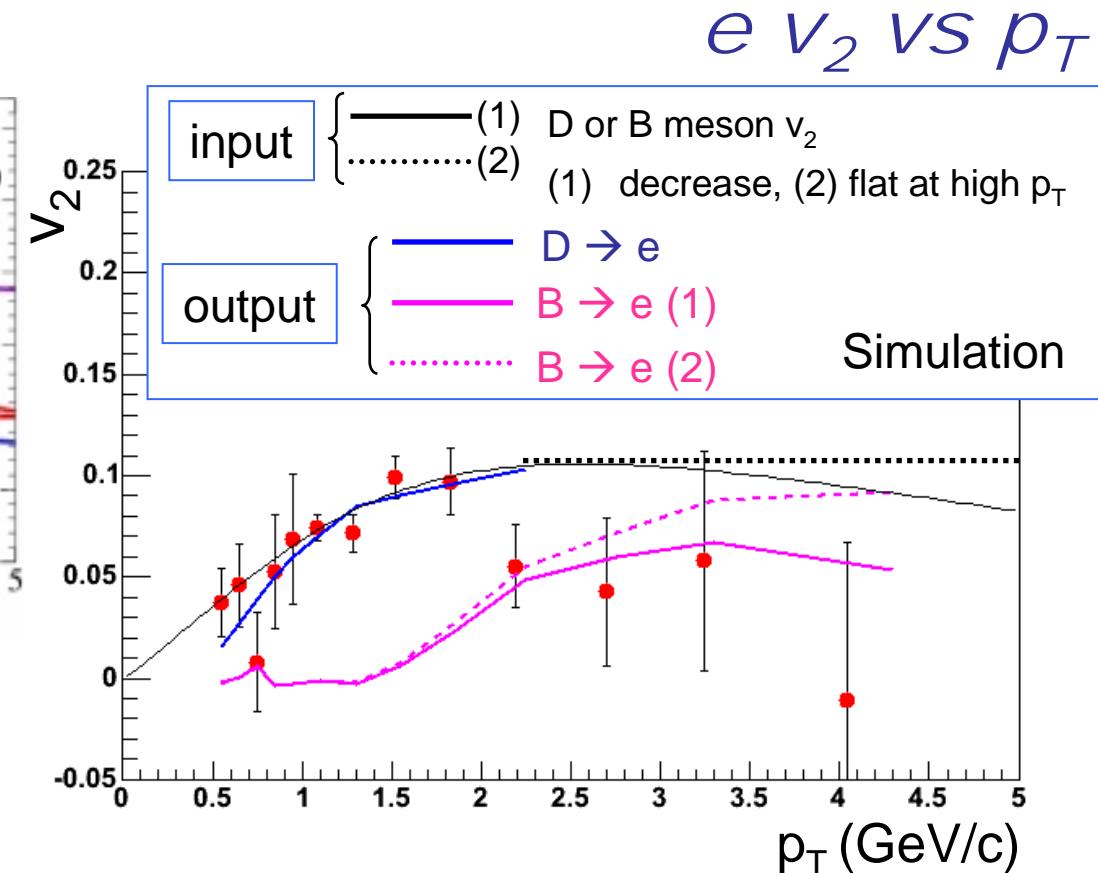
b quark contribution ?

H. Hees, V. Greco, R. Rapp: PRC 73,
034913 (2006)

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SQM 2006, S. Sakai

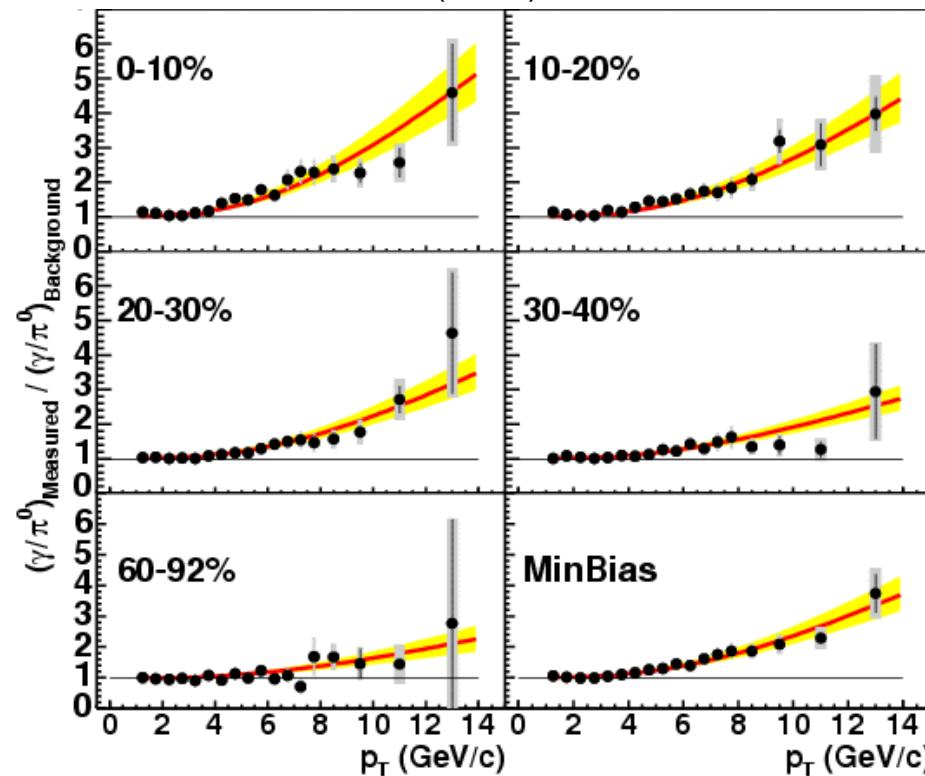


- *High p_T drop might be explained by B meson contribution*

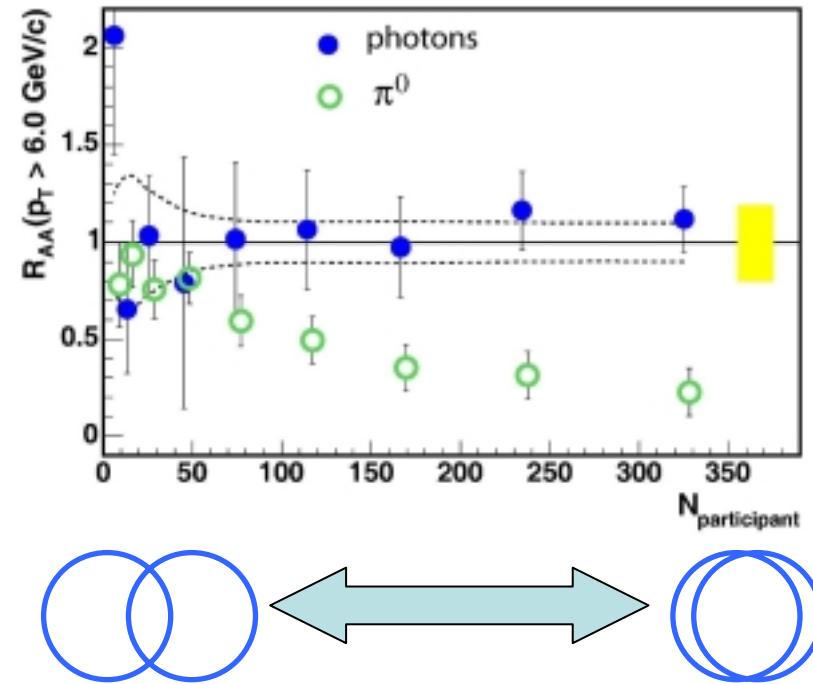
3. Direct γV^2

Clear Direct γ signal

PRL 94, 232301 (2005)

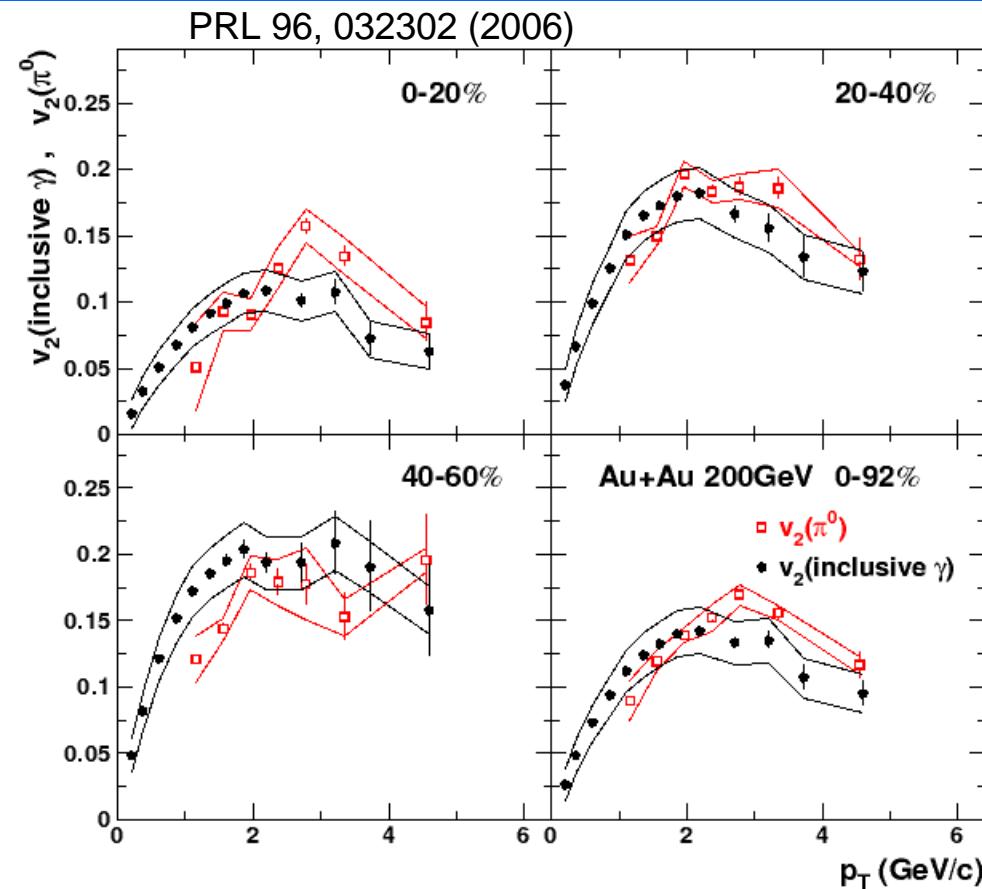


$$R_{AA} = \frac{Yield_{AA}}{\langle N_{coll} \rangle Yield_{pp}}$$

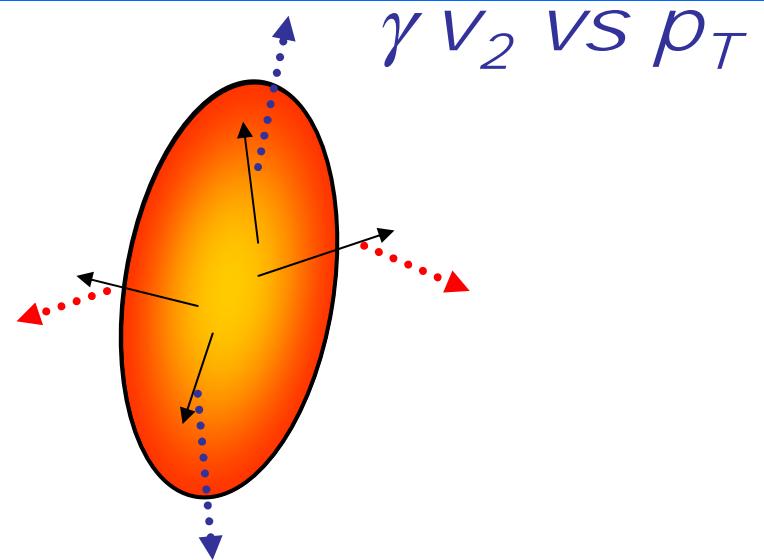


- Large direct γ excess
- π^0 is suppressed but direct γ not
 - Both results are consistent with pQCD

Possible 3 different scenarios

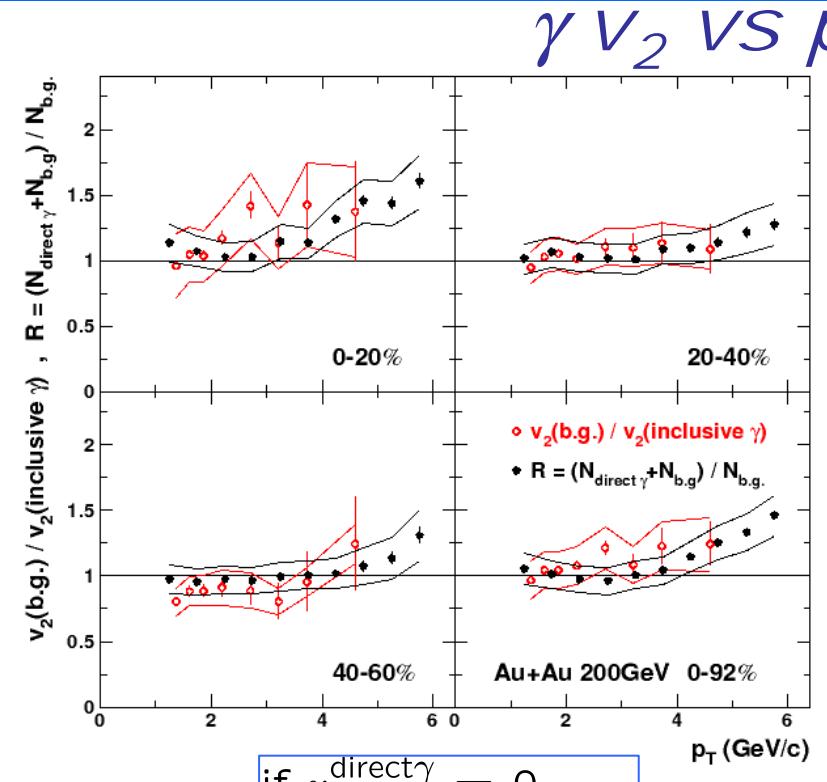
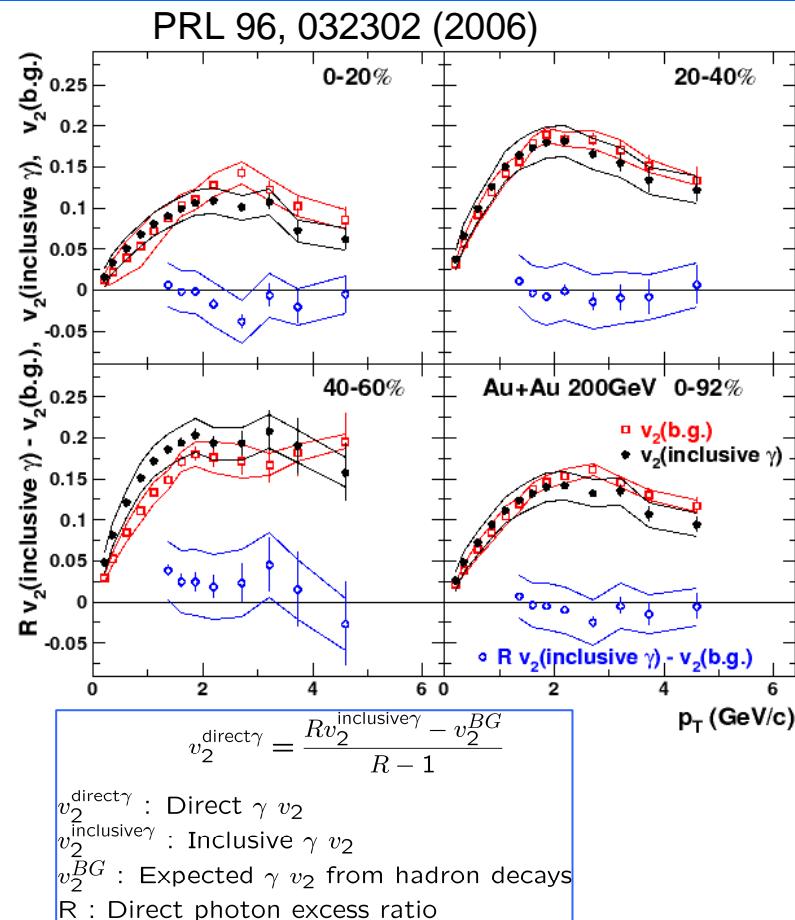


- *Inclusive γ*
 - Consistent with expected γ v_2 from hadron decays



- *Direct γv_2*
 1. Hard scattering
 - $v_2 = 0$
 2. Parton fragmentation
 - $v_2 > 0$ →
 3. Bremsstrahlung
 - $v_2 < 0$ ←

$v_2^{\text{direct}\gamma} = 0 ?$



- *Direct γv_2*
 - Direct γ excess ratio is consistent with $v_2^{\text{BG}}/v_2^{\text{inclusive}\gamma}$, suggest $v_2^{\text{direct}\gamma} = 0$
 - Favors prompt photon production for dominant source of direct γ

Conclusions

- *Elliptic Flow is powerful tool to study hot and dense matter at RHIC*
- ϕ meson → *Partonic degrees of freedom*
 - Hydro. mass ordering for $p_T < 2 \text{ GeV}/c$
 - For $p_T > 2 \text{ GeV}/c$, $v_2(\phi)$ prefer quark composition not mass
 - Hydro + Nquark scaling works for ϕ meson as well as other hadrons
- Heavy flavor electron → *Thermalization*
 - Consistent with non-zero charm flow, suggest thermalization of c quark as well as light quarks
 - Bottom contribution at high p_T need to be studied experimentally
- Direct γ → *Coming soon ...*
 - $v_2^{\text{direct}} = 0$, consistent with the scenario of direct γ production from initial hard scattering
 - Year-4 data may enable us to reduce statistical error bars, and extend p_T reach, and to measure thermal γv_2

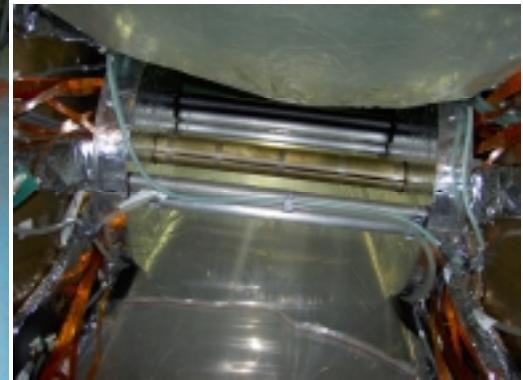
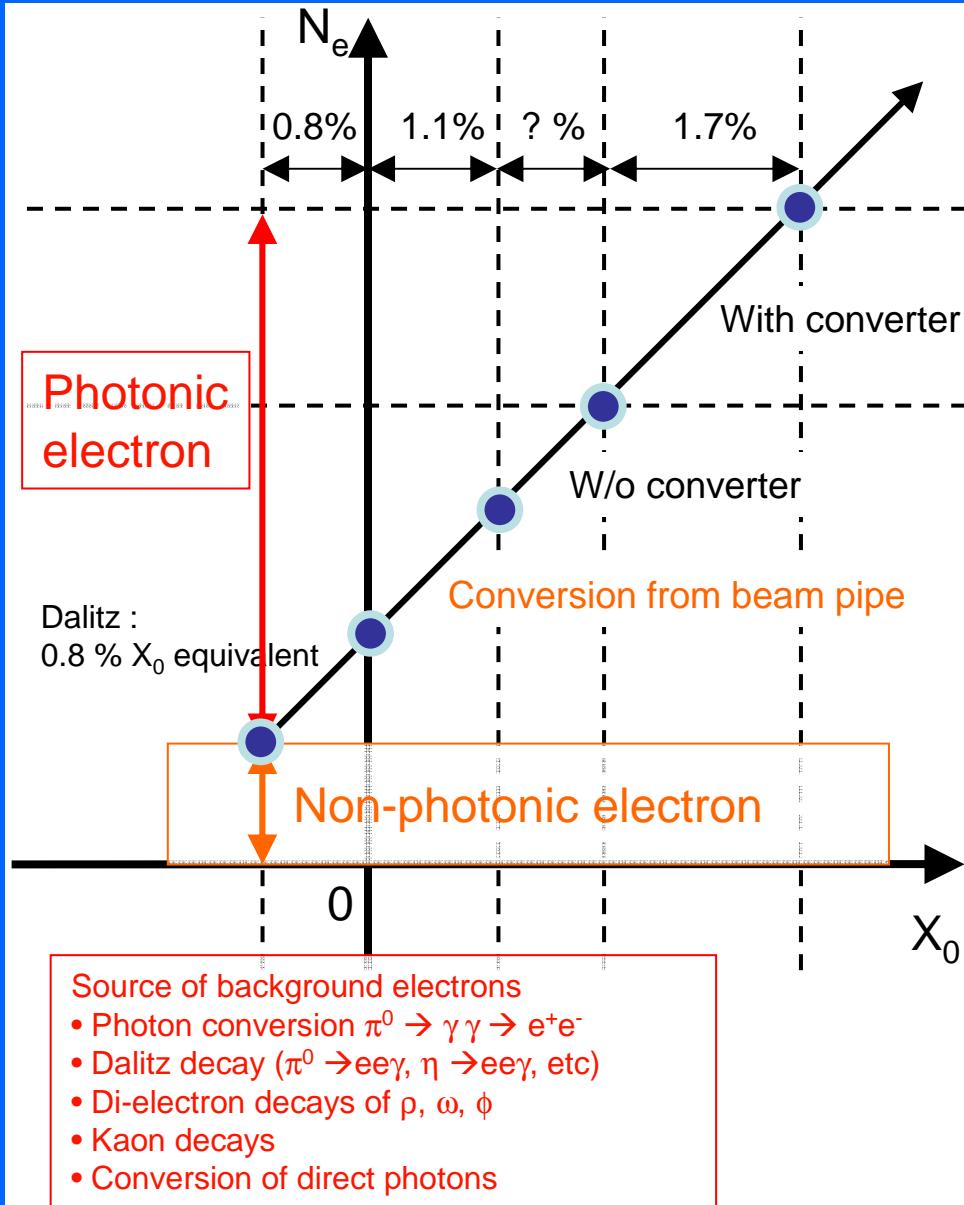
Thank you



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Back up

Converter Subtraction method



Photon Converter (Brass 1.7 % X_0) around beam pipe

$$\begin{aligned} N^e &= N^{np} + N^p \\ N_c^e &= N^{np} + R * N^p \\ R &= \frac{\text{Photonic e w. Converter}}{\text{Photonic e w/o Converter}} \end{aligned}$$

N^{np} : Non-photonic electron yield

N^p : Photonic electron yield

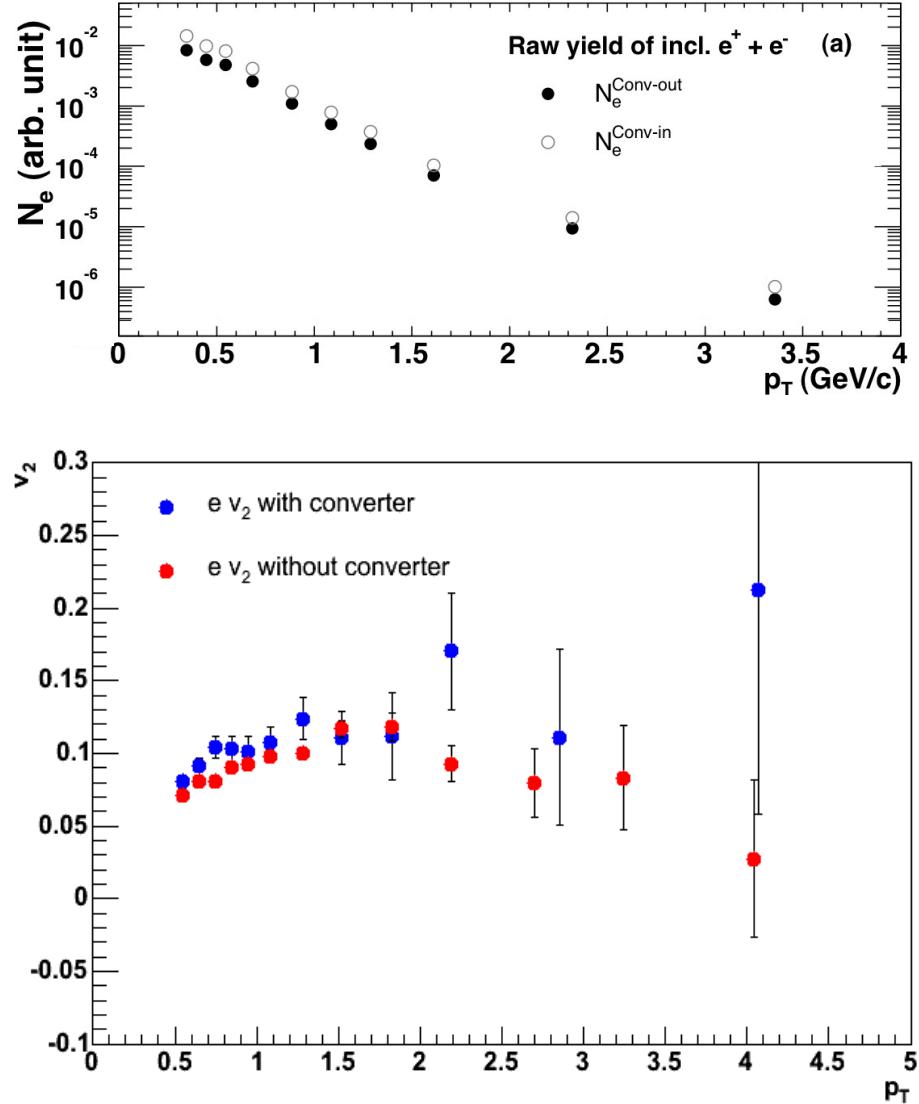
N^e : Inclusive electron yield w/o Converter

N_c^e : Inclusive electron yield w. Converter

$$N^p = \frac{N_c^e - N^e}{R - 1}$$

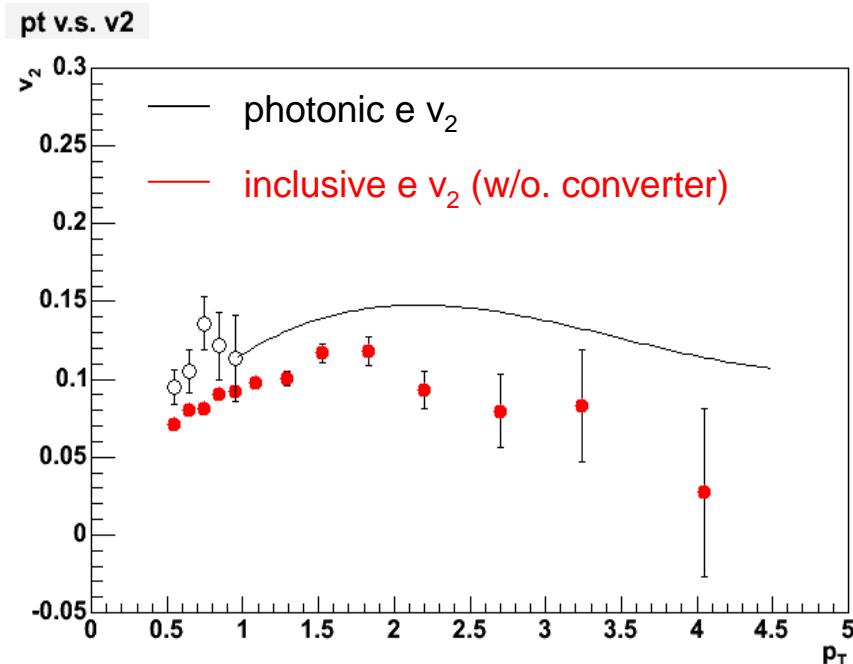
$$N^{np} = \frac{R * N^e - N_c^e}{R - 1}$$

Inclusive electron v_2 (w., w/o. converter)



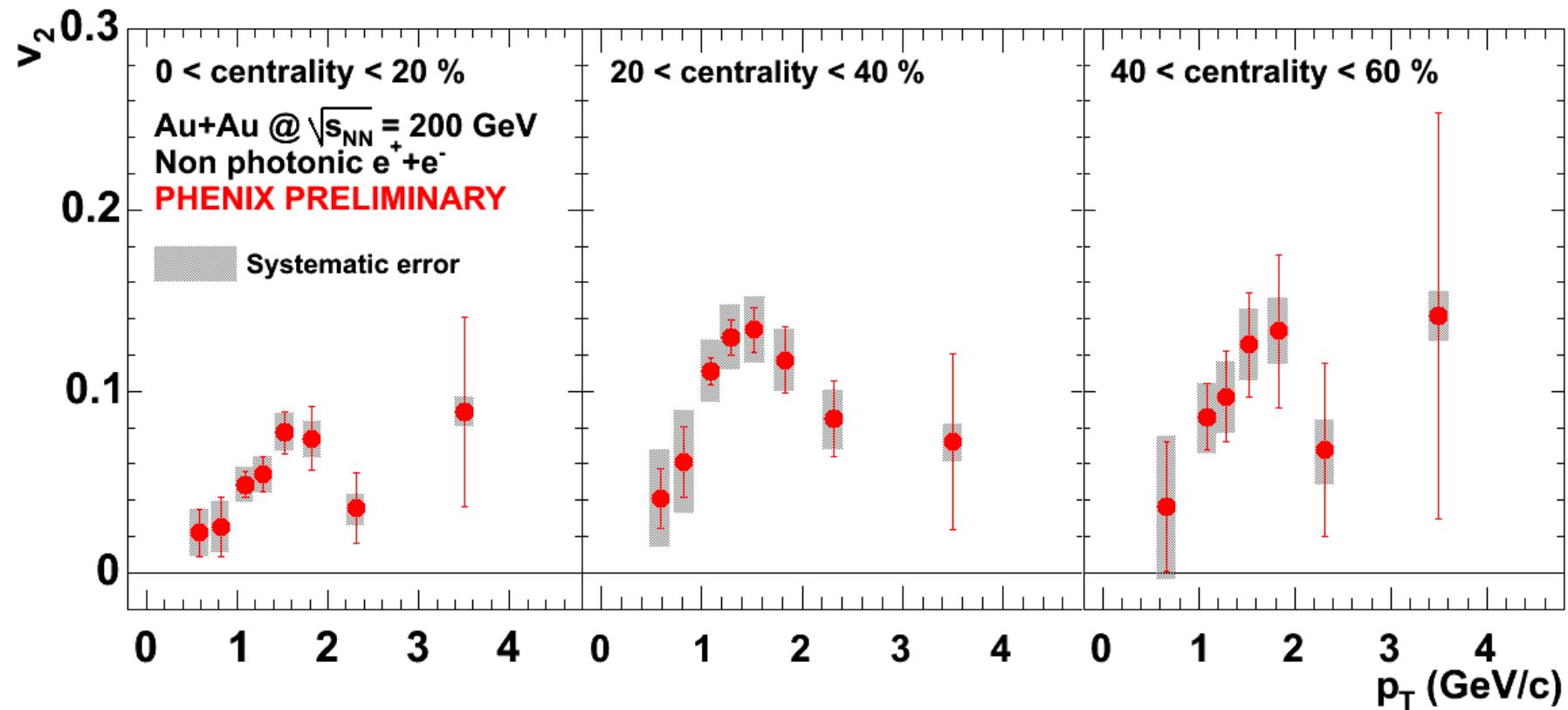
- *Converter subtraction method*
 - Inclusive electron v_2 w. and w/o. converter.
 - Clear difference between them.
 - Electron v_2 with converter include large photonic component.

Inclusive & photonic electron v_2



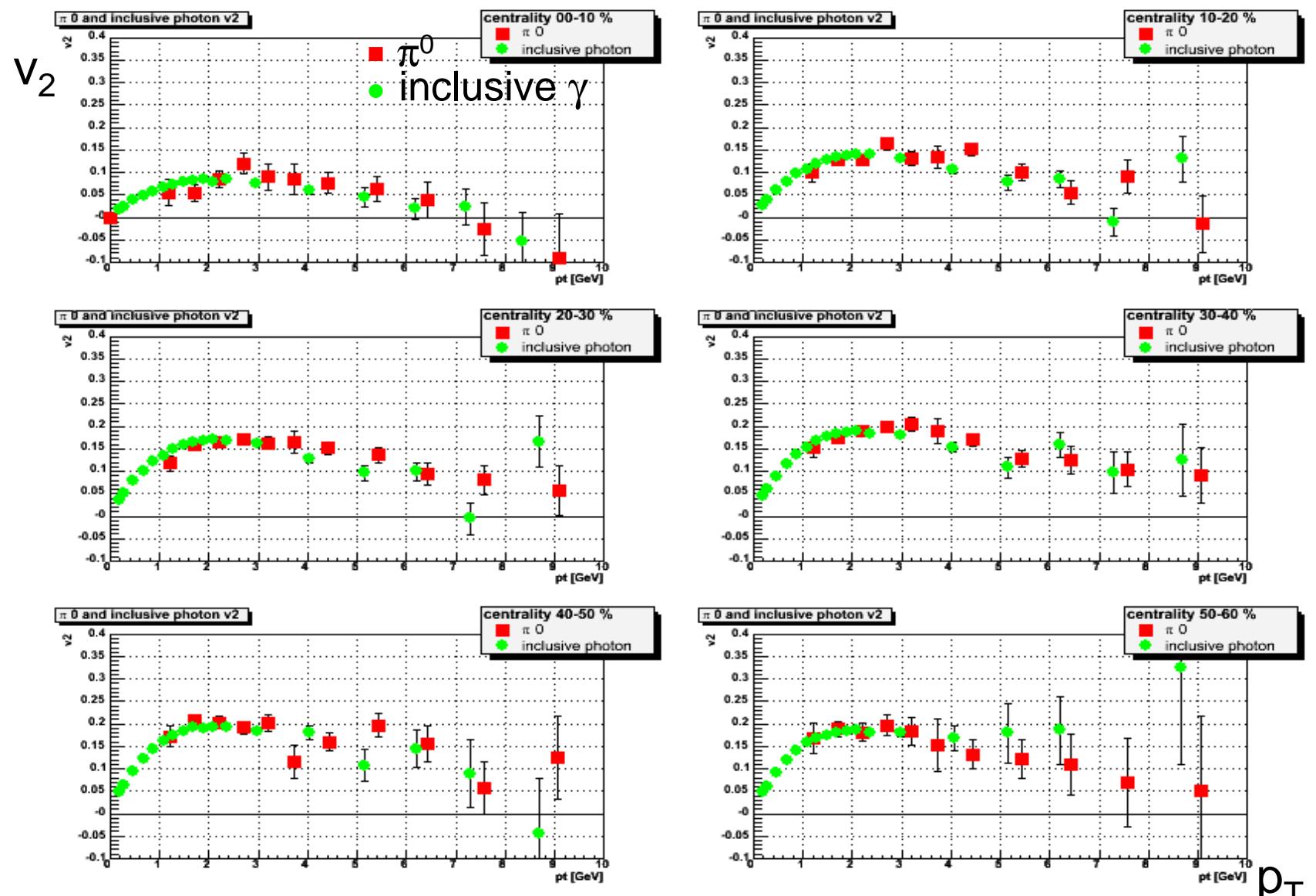
- Photonic electron v_2
 - $p_T < 1 \text{ GeV}/c$
→ Converter method
 - $p_T > 1 \text{ GeV}/c$
→ Simulation
 - $v_2(\text{inclusive}) < v_2(\text{photonic})$
→ $v_2(\text{non-photonic}) < v_2(\text{photonic})$

Centrality dependence

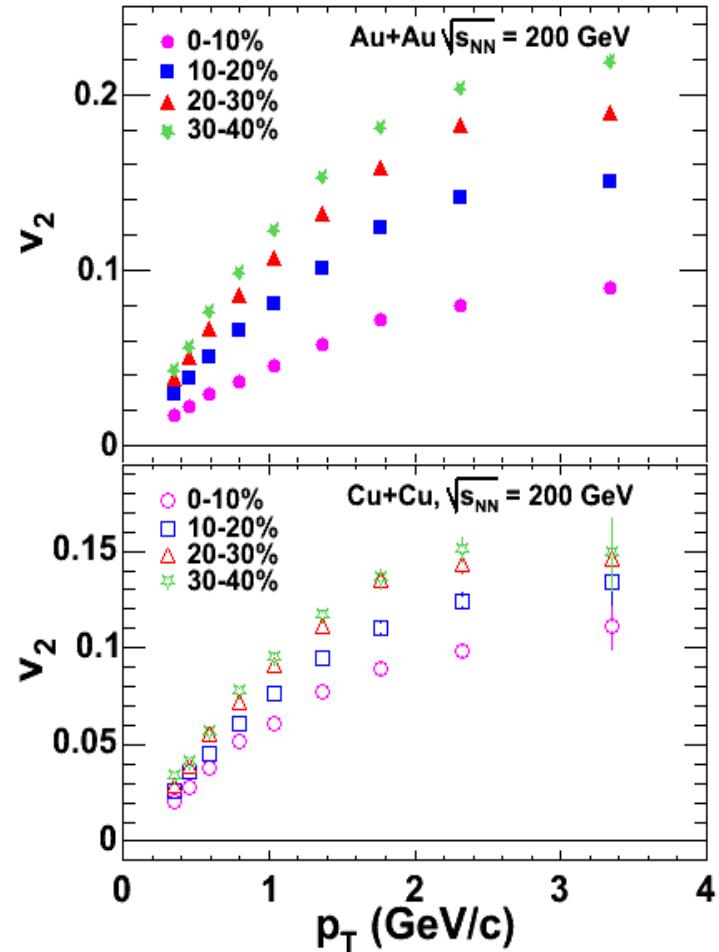


- Non zero heavy flavor electron v_2 !

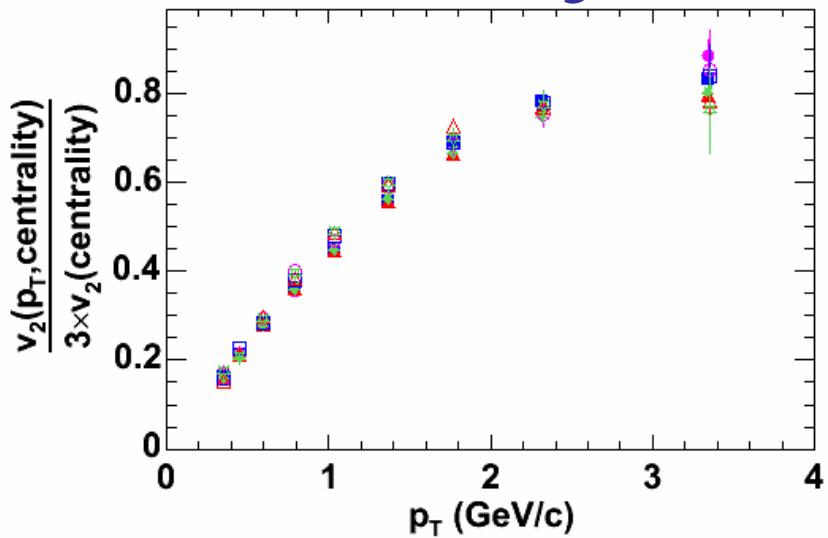
Run4 inclusive γV_2



Independent on system size

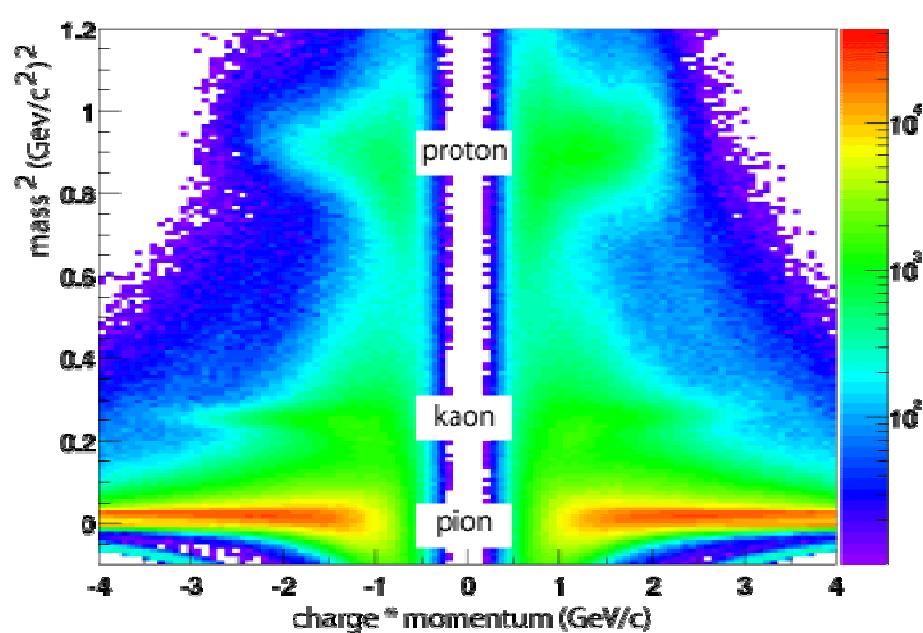
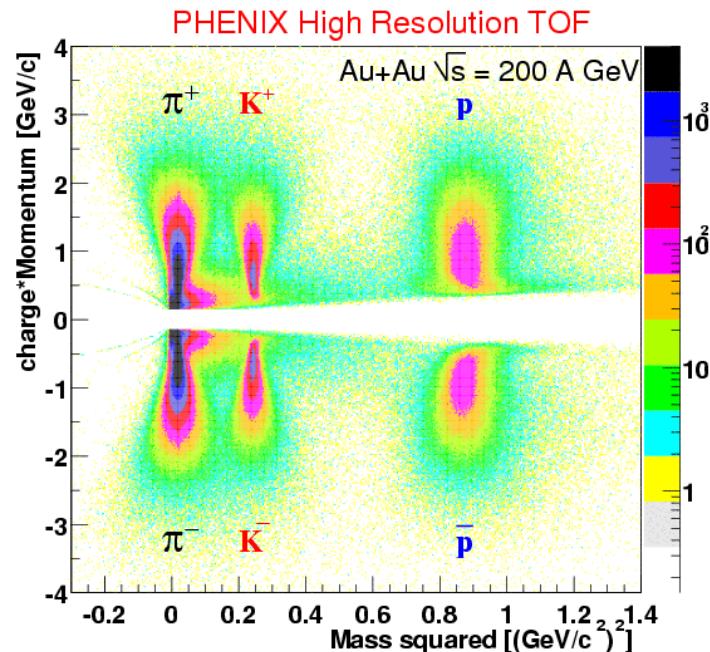


Eccentricity scaling



- *Eccentricity scaling*
 - A wide range of centrality
 - Independent of system size
- *Integrated $v_2 \propto$ eccentricity*
 - Reduce systematic error from eccentricity calculation
 - Cancel systematic error by the ratio of $v_2(p_T)$ / (integrated v_2)

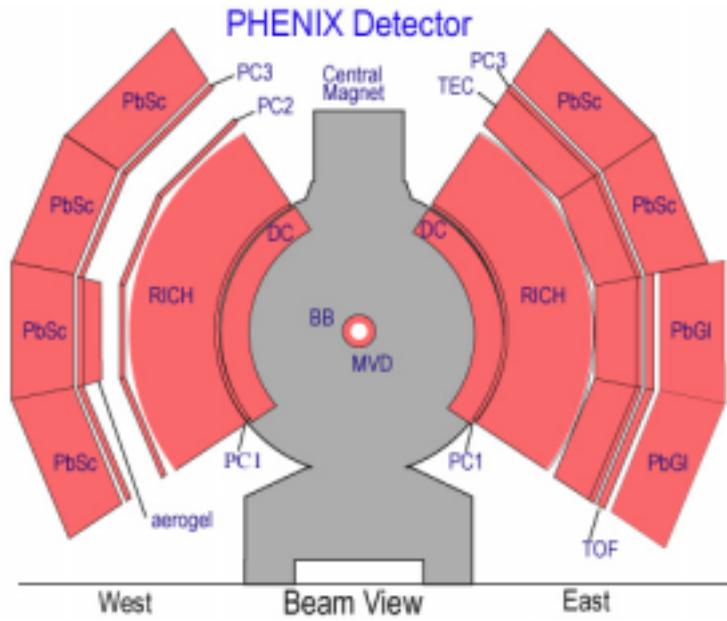
Hadron identification



- *Time-of-flight*
 - $|\phi| < \pi/4$, $|\eta| < 0.35$
 - Timing resolution ~ 120 ps
 - π/K separation ~ 2 GeV/c
 - K/p separation ~ 4 GeV/c

- *EM Calorimeter*
 - $|\phi| < \pi/2$, $|\eta| < 0.35$
 - Timing resolution ~ 400 ps
 - π/K separation ~ 1 GeV/c
 - K/p separation ~ 2 GeV/c

The PHENIX experiment



- *Acceptance*
 - Central arm: $|\Delta\phi| < \pi$, $|\Delta\eta| < 0.35$
- *Centrality*
 - Beam-Beam Counter, Zero Degree Calorimeter.
- *Event plane*
 - BBC
- *Tracking*
 - Drift chamber, Pad chambers.
- *Particle identification*
 - Electron
 - Electro-Magnetic Calorimeter
 - Hadron
 - Time-of-Flight, Aerogel Cherenkov Counter, EMCal